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WNMA Project

Real-time crowd information using Bluetooth: a full-stack solution

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Outline

Introduction

Project Idea: is it possible to exploit Bluetooth to count how many people are there in a room / building and the occupancy trends?

- Seat availability in libraries (without reservation)
- Workforce management (effective deployment)
- Health-critical monitoring (pandemic)

Assumption: BT is a very diffused technology and nowadays most people have a BT-enabled device (smartphone, smartwatch, etc.) with them. Often it is turned on beacause of low energy consumption.

Scanner

The scanner is a device that periodically scans [1]the environment for Bluetooth devices and sends the data to the server.
Implemented in Go, can run both on Raspberry Pi and Arduino[2].

Features

- Low energy consumption
- Low cost hardware
- Easy deployment

Thanks to linux's crontab, the scanner can be scheduled to run at specific times, e.g. every 5 minutes.

[1] Use the go-bluetooth library and the Bluez DBus API
[2] Can be compiled for Arduino using TinyGo

Server

The server includes both a backend and a frontend developed in a product-ready fashion.

Backend

- Implemented in Go
- RESTful API
- Data storage: SQLite

Frontend

- Implemented in React
- Real-time data visualization

System Architecture

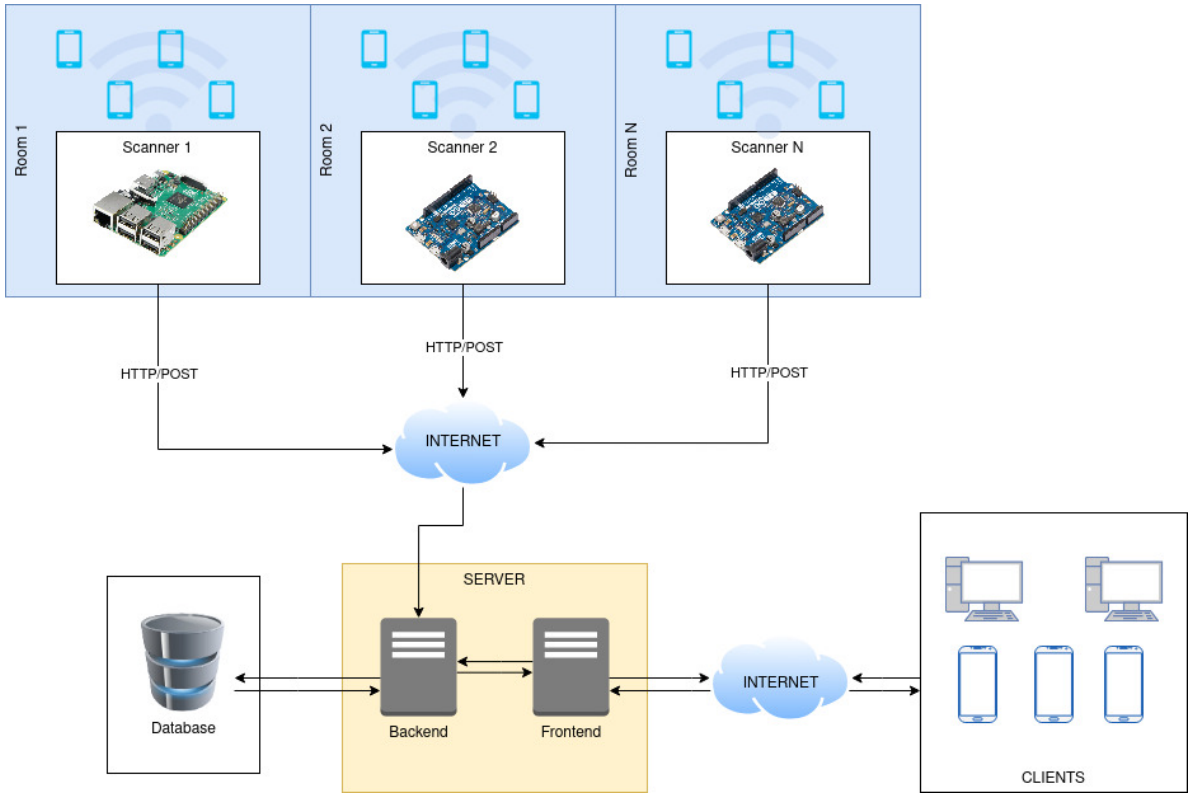


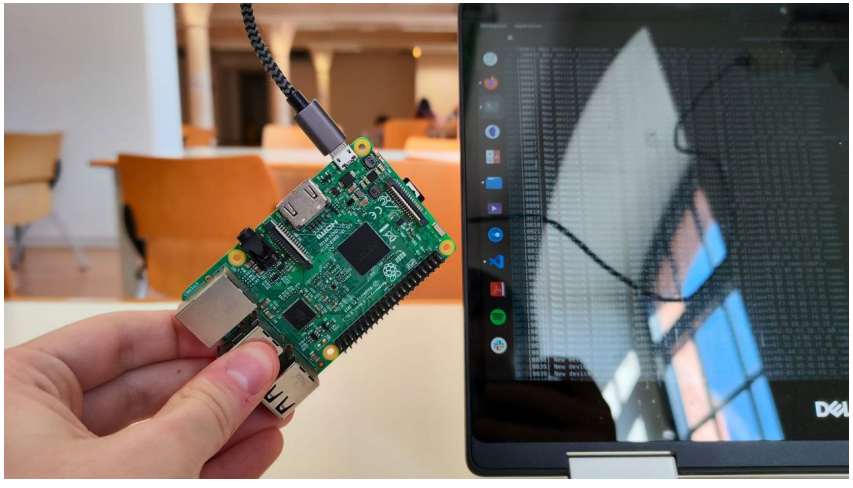
Figure: System architecture

Field test

The system has been tested in a real environment: a small local library.

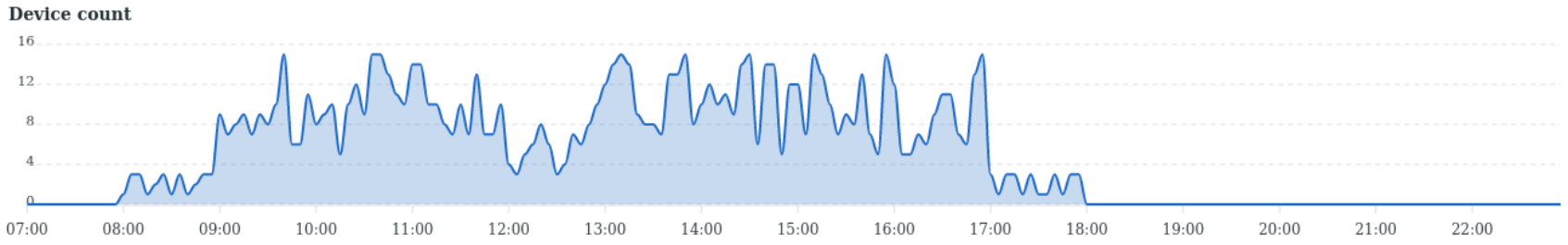
- The scanner (Raspberry Pi) has been placed in a central position
- To avoid hosting costs, the server has been deployed on the Raspberry loopback interface
- Three days of data collection with few people in the library

Field test



```
INFO[0001] New device discovered: addr=68:7F:57:01:77:A9 rssi=-100 alias=68-7F-57-01-77-A9 name=
INFO[0001] New device discovered: addr=45:81:D5:55:3B:02 rssi=-95 alias=45-81-D5-55-3B-02 name=
INFO[0001] New device discovered: addr=5C:3C:AE:22:B5:E6 rssi=-91 alias=5C-3C-AE-22-B5-E6 name=
INFO[0001] New device discovered: addr=69:A5:A7:04:F8:1E rssi=-92 alias=69-A5-A7-04-F8-1E name=
INFO[0002] New device discovered: addr=63:93:2E:FB:EA:DE rssi=-87 alias=63-93-2E-FB-EA-DE name=
INFO[0002] New device discovered: addr=47:C8:15:8C:6A:F3 rssi=-77 alias=47-C8-15-8C-6A-F3 name=
INFO[0002] New device discovered: addr=40:F0:D8:B9:29:C3 rssi=-94 alias=40-F0-D8-B9-29-C3 name=
INFO[0002] New device discovered: addr=54:B4:3E:05:7F:88 rssi=-87 alias=54-B4-3E-05-7F-88 name=
INFO[0002] New device discovered: addr=64:65:D9:F8:13:B6 rssi=-98 alias=64-65-D9-F8-13-B6 name=
INFO[0002] New device discovered: addr=7B:4B:A3:E3:96:17 rssi=-90 alias=7B-4B-A3-E3-96-17 name=
INFO[0002] New device discovered: addr=59:06:7F:D2:29:8E rssi=-102 alias=59-06-7F-D2-29-8E name=
INFO[0002] New device discovered: addr=77:ED:8A:A9:75:55 rssi=-93 alias=77-ED-8A-A9-75-55 name=
INFO[0002] New device discovered: addr=6A:32:99:3E:98:48 rssi=-94 alias=6A-32-99-3E-98-48 name=
INFO[0002] New device discovered: addr=7C:5C:F8:3E:87:66 rssi=-88 alias=ASUS-I7 name=ASUS-I7
INFO[0002] New device discovered: addr=60:57:18:D4:76:77 rssi=-64 alias=DESKTOP-MFRQ6ET name=DESKTOP-MFRQ6ET
INFO[0002] New device discovered: addr=58:78:00:52:5B:3B rssi=-94 alias=58-78-00-52-5B-3B name=
INFO[0002] New device discovered: addr=43:6D:42:09:04:89 rssi=-81 alias=43-6D-42-09-04-89 name=
INFO[0003] New device discovered: addr=4A:51:B6:2D:56:03 rssi=-91 alias=4A-51-B6-2D-56-03 name=
INFO[0003] New device discovered: addr=5A:8F:2D:44:21:B8 rssi=-89 alias=5A-8F-2D-44-21-B8 name=
INFO[0003] New device discovered: addr=43:EA:4B:F2:BD:B1 rssi=-80 alias=43-EA-4B-F2-BD-B1 name=
INFO[0003] New device discovered: addr=00:7C:2D:FB:D9:05 rssi=-95 alias=00-7C-2D-FB-D9-05 name=
INFO[0003] New device discovered: addr=76:2D:6A:C6:3C:7B rssi=-83 alias=76-2D-6A-C6-3C-7B name=
INFO[0003] New device discovered: addr=59:61:01:44:B8:30 rssi=-87 alias=59-61-01-44-B8-30 name=
INFO[0003] New device discovered: addr=54:0E:58:C7:72:CE rssi=-92 alias=54-0E-58-C7-72-CE name=
INFO[0004] New device discovered: addr=46:02:6C:4F:B4:BB rssi=-97 alias=46-02-6C-4F-B4-BB name=
INFO[0004] New device discovered: addr=7C:91:DE:CC:EC:E6 rssi=-80 alias=7C-91-DE-CC-EC-E6 name=
INFO[0004] New device discovered: addr=A0:43:DB:00:97:C5 rssi=-78 alias=ARG4038853* name=ARG4038853*
INFO[0004] New device discovered: addr=7B:45:7A:8E:DF:22 rssi=-98 alias=7B-45-7A-8E-DF-22 name=
INFO[0004] New device discovered: addr=5B:3E:30:C3:C7:F1 rssi=-94 alias=5B-3E-30-C3-C7-F1 name=
INFO[0004] New device discovered: addr=4D:63:4D:EE:C5:AA rssi=-85 alias=4D-63-4D-EE-C5-AA name=
INFO[0004] New device discovered: addr=55:65:04:51:59:98 rssi=-101 alias=55-65-04-51-59-98 name=
INFO[0005] New device discovered: addr=4C:9C:95:66:90:5D rssi=-99 alias=4C-9C-95-66-90-5D name=
INFO[0005] New device discovered: addr=45:F9:8A:C3:54:61 rssi=-97 alias=45-F9-8A-C3-54-61 name=
INFO[0005] New device discovered: addr=65:41:59:76:31:C5 rssi=-92 alias=65-41-59-76-31-C5 name=
INFO[0006] New device discovered: addr=5D:16:84:4E:DA:23 rssi=-86 alias=5D-16-84-4E-DA-23 name=
INFO[0006] New device discovered: addr=B0:52:16:AC:26:32 rssi=-89 alias=LAPTOP-1E7595GA name=LAPTOP-1E7595GA
INFO[0007] New device discovered: addr=4F:F0:D9:50:69:44 rssi=-86 alias=4F-F0-D9-50-69-44 name=
INFO[0007] New device discovered: addr=61:84:50:8E:FE:7A rssi=-97 alias=61-84-50-8E-FE-7A name=
INFO[0007] New device discovered: addr=70:AB:36:53:1E:2B rssi=-87 alias=70-AB-36-53-1E-2B name=
INFO[0007] New device discovered: addr=65:FF:92:85:84:3A rssi=-80 alias=65-FF-92-85-84-3A name=
INFO[0008] New device discovered: addr=65:C4:28:E2:53:75 rssi=-80 alias=65-C4-28-E2-53-75 name=
INFO[0008] New device discovered: addr=4D:6C:6F:CE:24:3F rssi=-94 alias=4D-6C-6F-CE-24-3F name=
INFO[0008] New device discovered: addr=5E:7F:DD:F8:C4:BC rssi=-99 alias=5E-7F-DD-F8-C4-BC name=
INFO[0009] New device discovered: addr=7A:1F:55:24:83:78 rssi=-80 alias=7A-1F-55-24-83-78 name=
INFO[0009] New device discovered: addr=78:A6:8C:43:2E:AA rssi=-92 alias=78-A6-8C-43-2E-AA name=
INFO[0009] New device discovered: addr=47:51:B8:66:C6:57 rssi=-95 alias=02241204 name=02241204
INFO[0009] New device discovered: addr=22:14:70:E1:43:35 rssi=-100 alias=22-14-70-E1-43-35 name=
INFO[0010] New device discovered: addr=6D:D6:EB:4B:84:6F rssi=-97 alias=6D-D6-EB-4B-84-6F name=
INFO[0010] New device discovered: addr=48:8F:30:5A:2F:99 rssi=-94 alias=48-8F-30-5A-2F-99 name=
INFO[0010] New device discovered: addr=74:D7:B3:D4:73:40 rssi=-93 alias=74-D7-B3-D4-73-40 name=
```

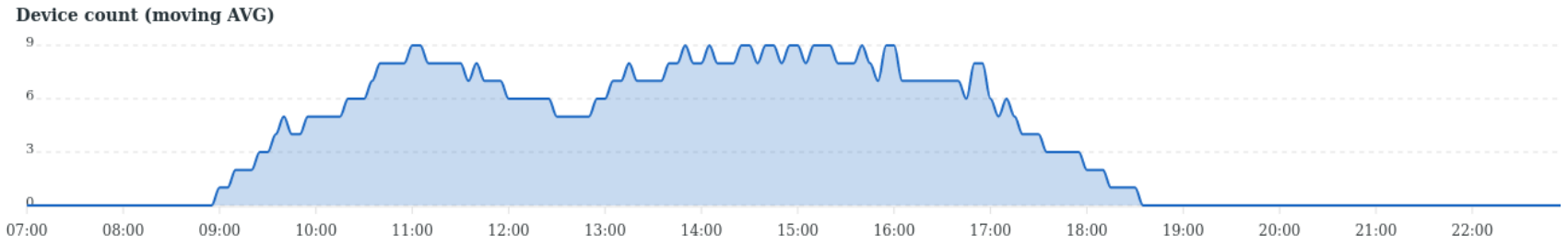
Results



Simple device count

- High variability in the number of devices detected
- occupancy trend is hard to detect
- Chart is day-based

Results

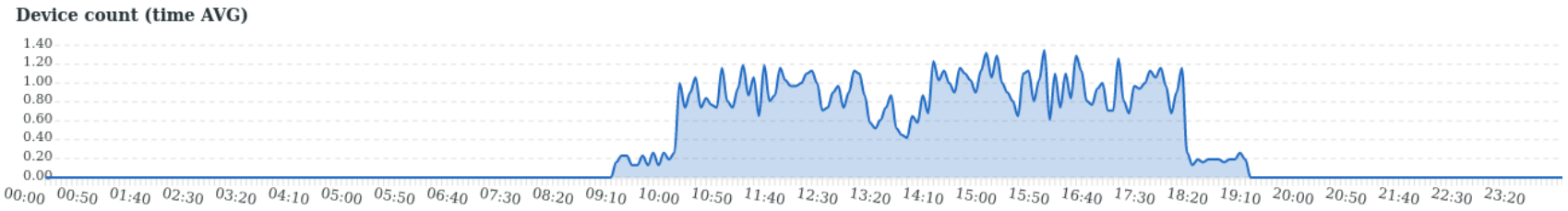


Moving average device count

- Moving average with window of 25 minutes
- Trend is more visible

$$SMA_k = \frac{p_{n-k+1} + p_{n-k+2} + \cdots + p_n}{k} = \frac{1}{k} \sum_{i=n-k+1}^{n} p_i \qquad (1)$$

Results



Average device count per time

```
SELECT scan.scanTime, COUNT(devices.id) AS numDevices FROM scan
LEFT JOIN devices ON scan.id = devices.scanID
WHERE scan.scannerID = ?
AND scan.scanTime BETWEEN ? AND ?
GROUP BY scan.scanTime;
```

Additional considerations

Privacy

- It may be possible to track user behaviour
- Data should be anonymized
- MAC randomization by Google and Apple helps

Data analysis: it is possible to further develop the system for advanced analysis of collected data.

- Affluence predictions
- Patterns
- User behaviour

Conclusions

The prototype has been successfully built as a complete product and seems to work as intended.

Problems

- Test data is insufficient: few days with small amount of people
- Not everyone has BT active
- People may have multiple BT devices
- Results may vary by locations (universities vs post office)

Conclusions

Further test and better data analysis are needed to evaluate the system's effectiveness.

Thank you for your attention!